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van Sprang et al.

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(54) **LED MODULE**

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Related U.S. Application Data

(63) Continuation of application No. 12/994,867, filed as application No. PCT/IB2009/052264 on May 29, 2009, now Pat. No. 8,410,504.

(30) **Foreign Application Priority Data**

Jun. 10, 2008 (EP) 08157943

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H01L 33/50 (2010.01)
H01L 33/44 (2010.01)
H05B 33/22 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 33/50*** (2013.01); ***H01L 33/44*** (2013.01); ***H05B 33/22*** (2013.01); *H01L 2224/48091* (2013.01); *H01L 2224/48247* (2013.01)

(58) **Field of Classification Search**
CPC . H01L 31/0232; H01L 33/405; H01S 5/0601; H01S 3/08059
USPC 257/40, 98
See application file for complete search history.

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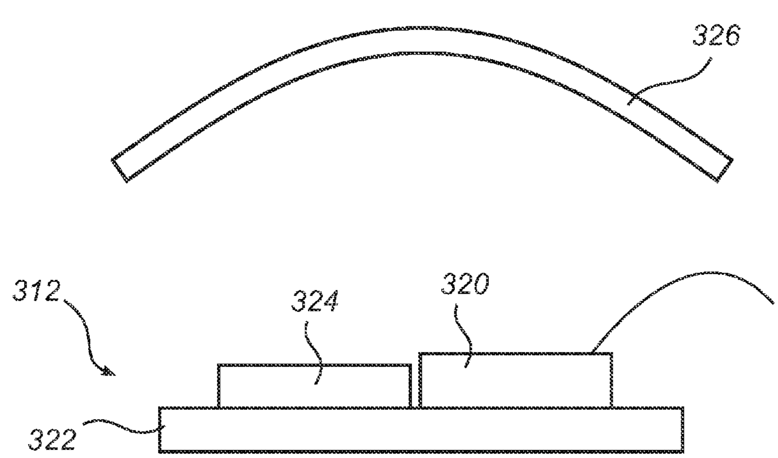
(57) **ABSTRACT**

The present invention relates to a LED module which converts pump light from a LED chip (**120**) to light at another wavelength, which is emitted from the module. The conversion takes place in a portion of a luminescent material (**124**). The color purity of the LED module is enhanced by reducing any leakage of pump light using a reflector in combination with an absorber. In one embodiment, the absorber is integrated as one or several thin absorbing layers between the layers of a multi-layer reflection filter (**126**); this may yield an even higher reduction of pump light leakage from the module.

12 Claims, 6 Drawing Sheets



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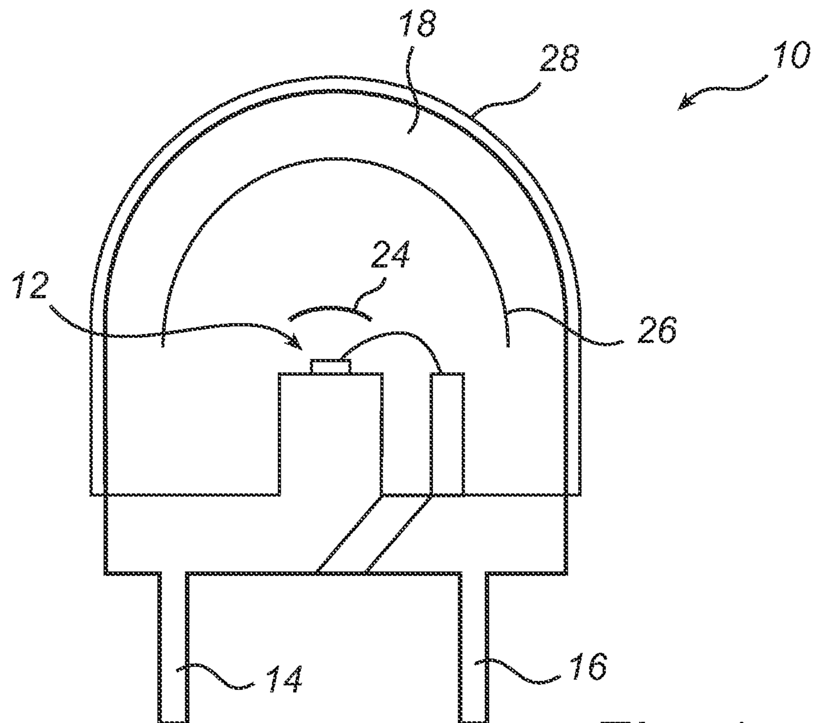


Fig. 1

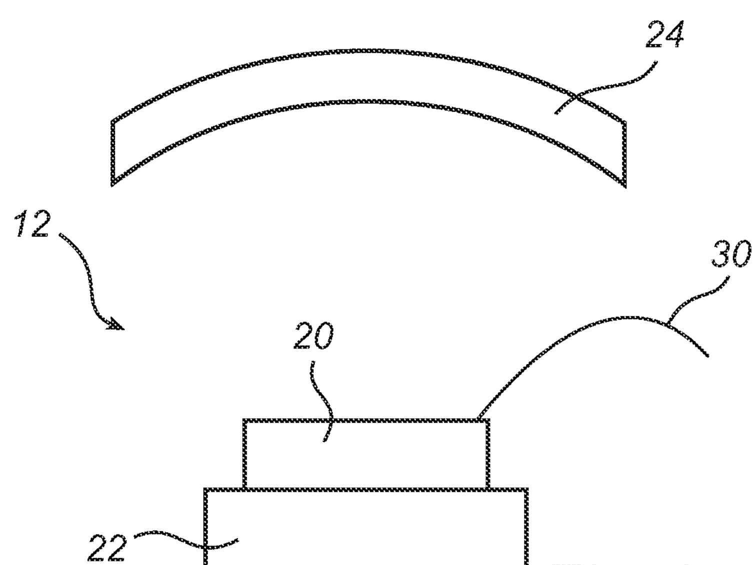


Fig. 2

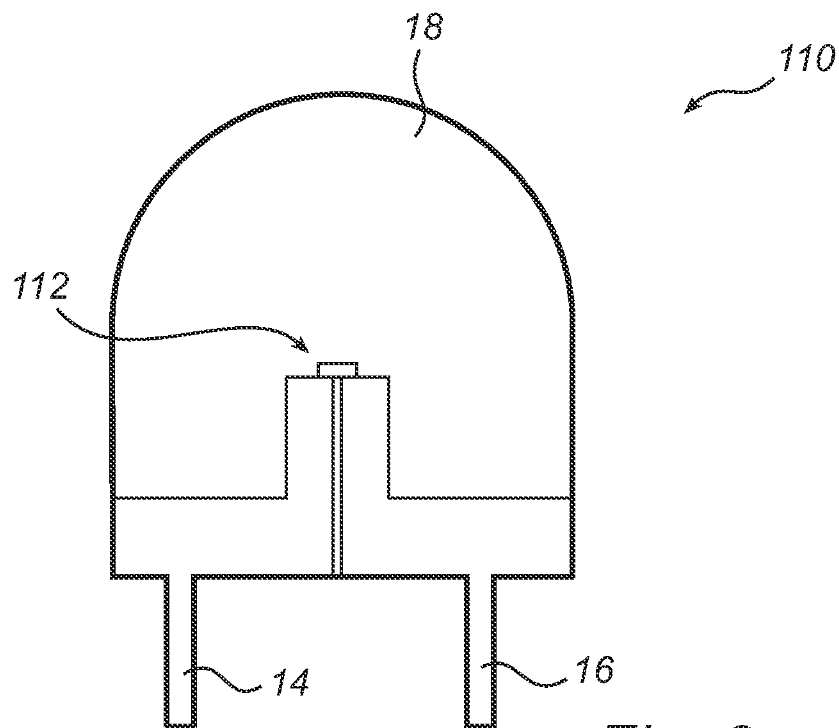


Fig. 3

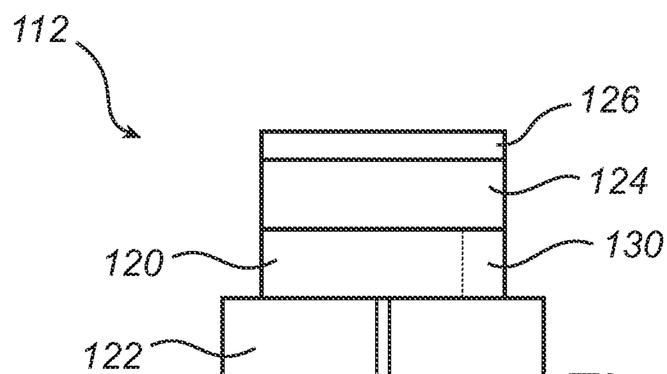
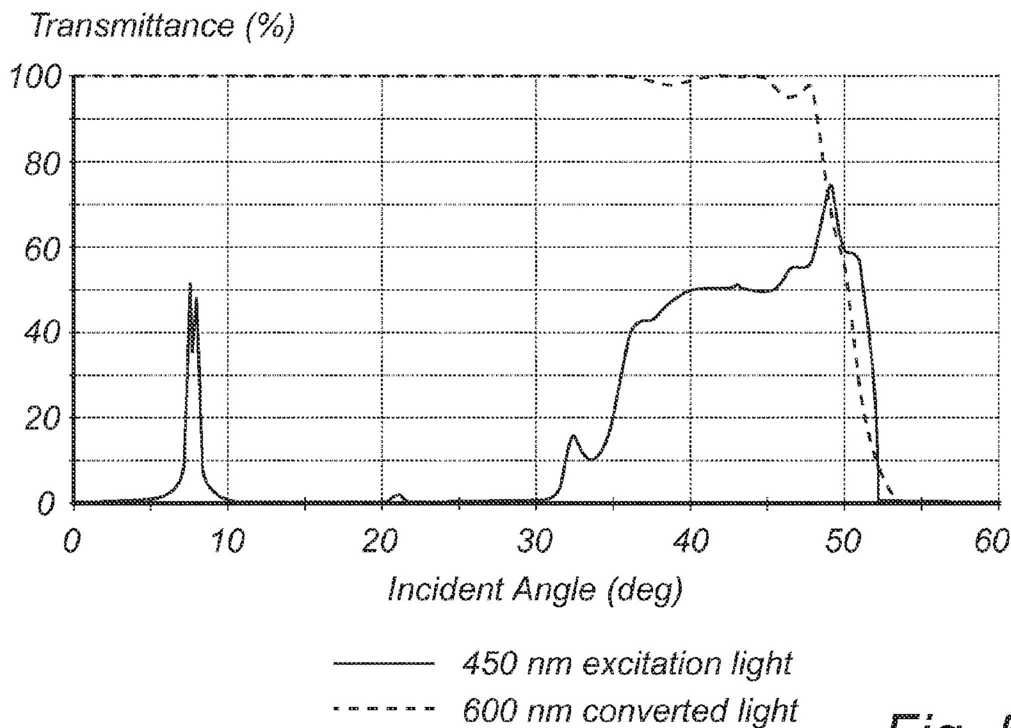


Fig. 4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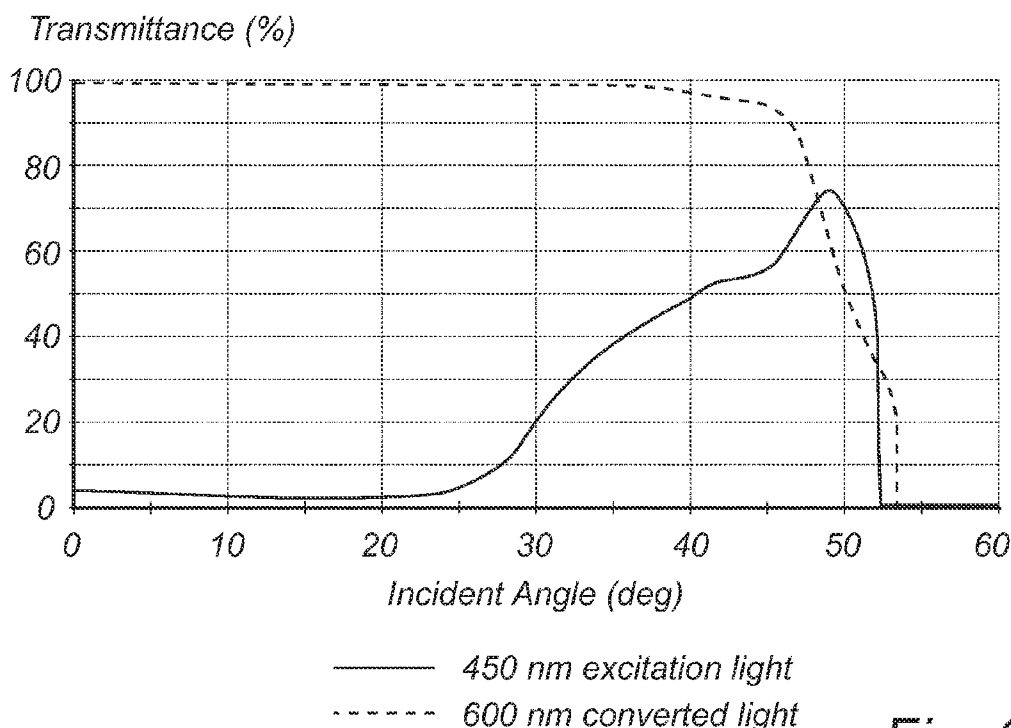
60
40
20
0
0
10
20
30
40
50
60
Incident Angle (deg)
450 nm excitation light
600 nm converted light

Fig. 5


Transmittance (%)
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600 nm converted light

Fig. 6

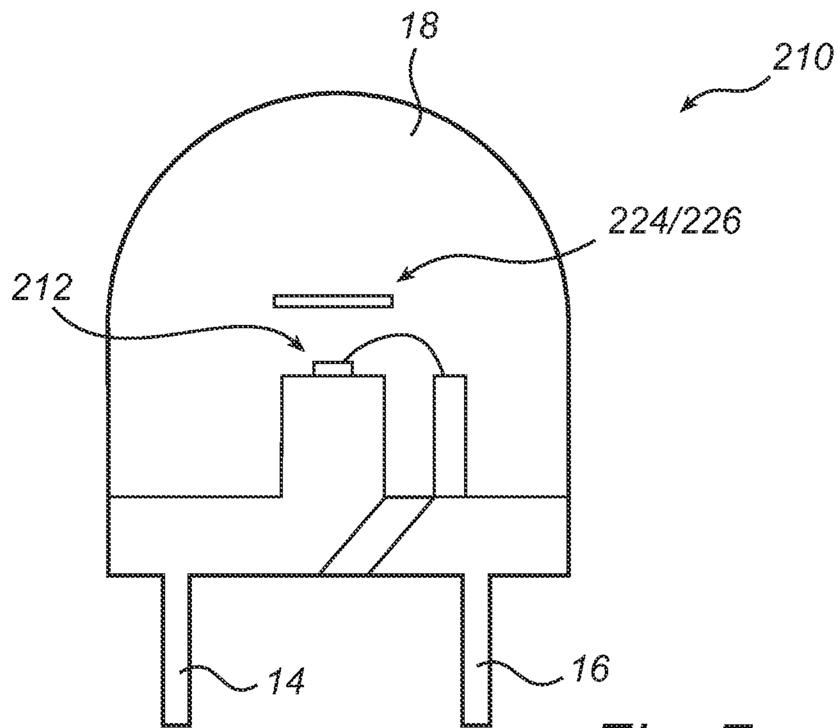

Fig. 7

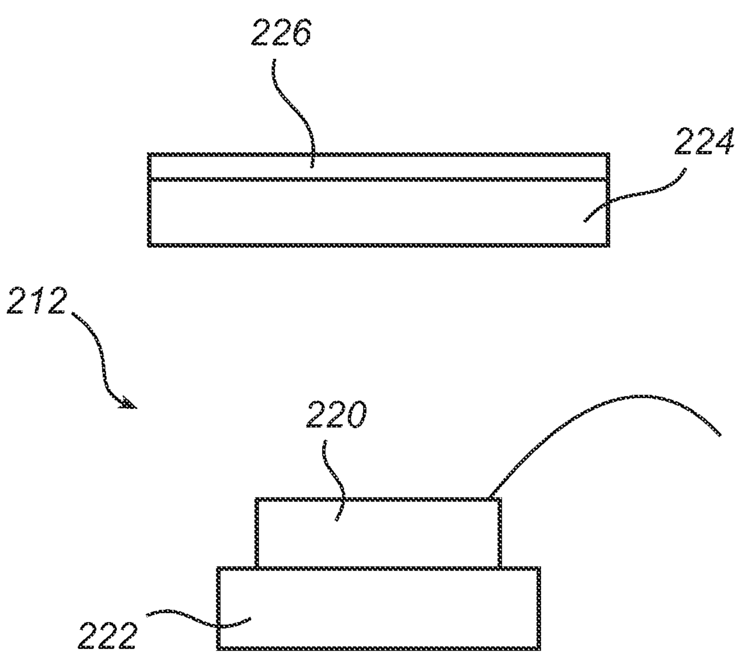

Fig. 8

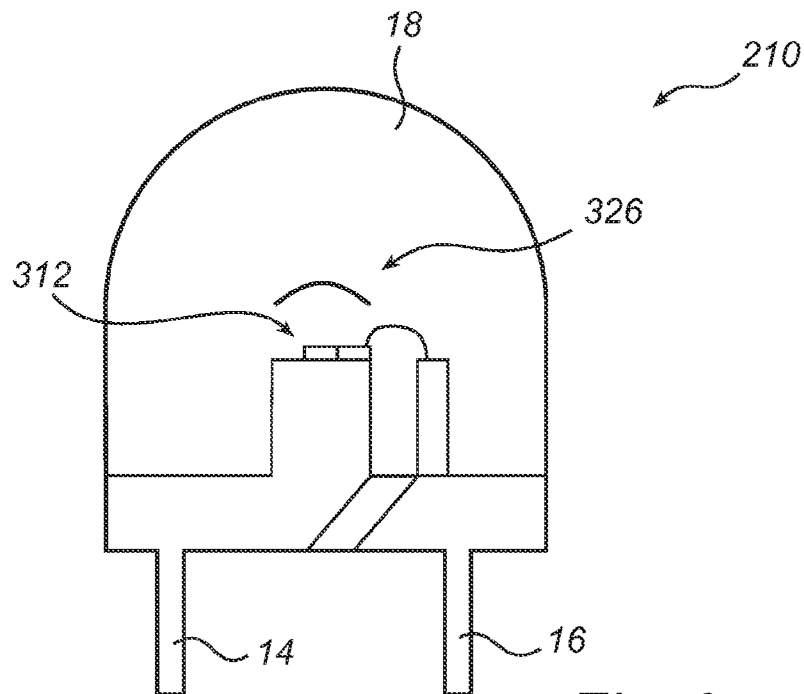

Fig. 9

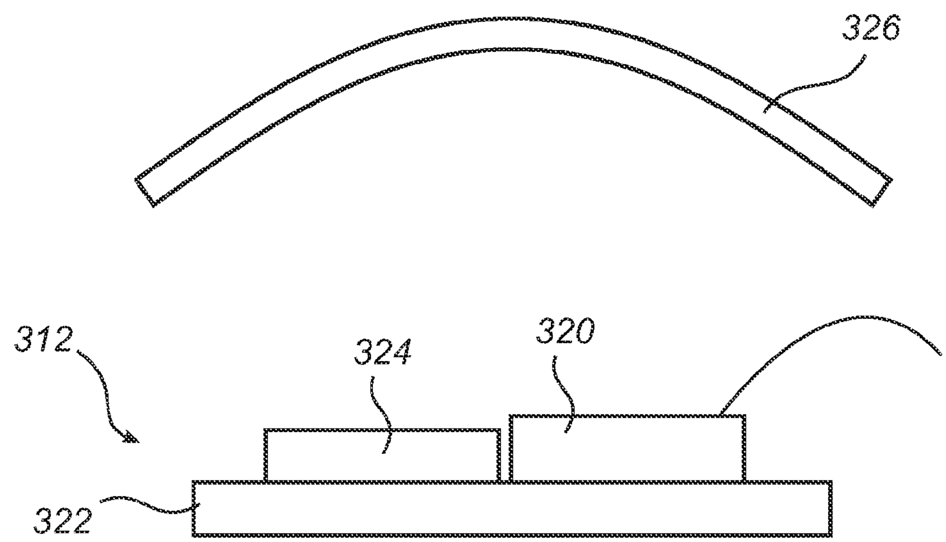

Fig. 10

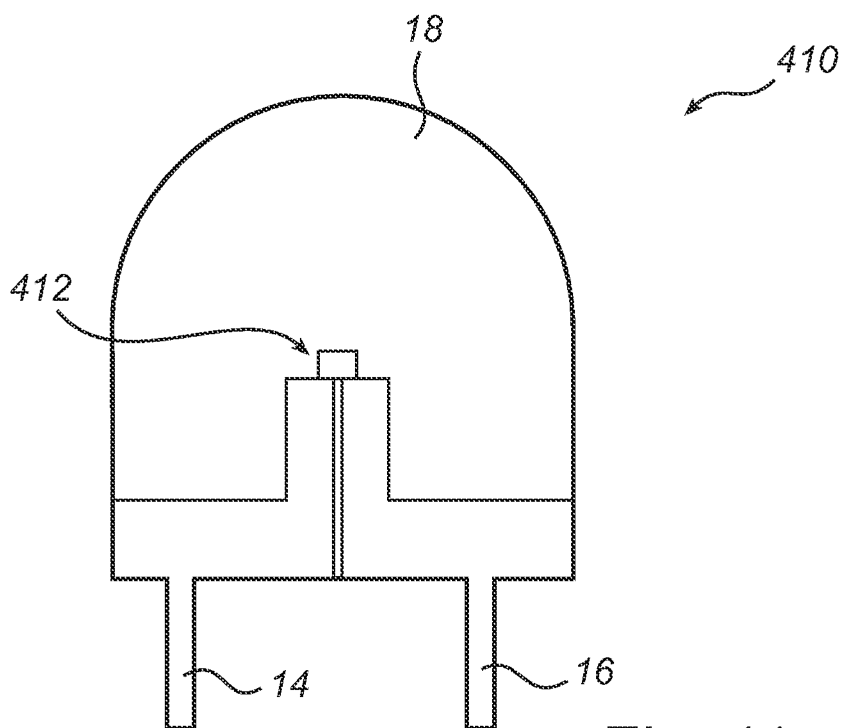

Fig. 11

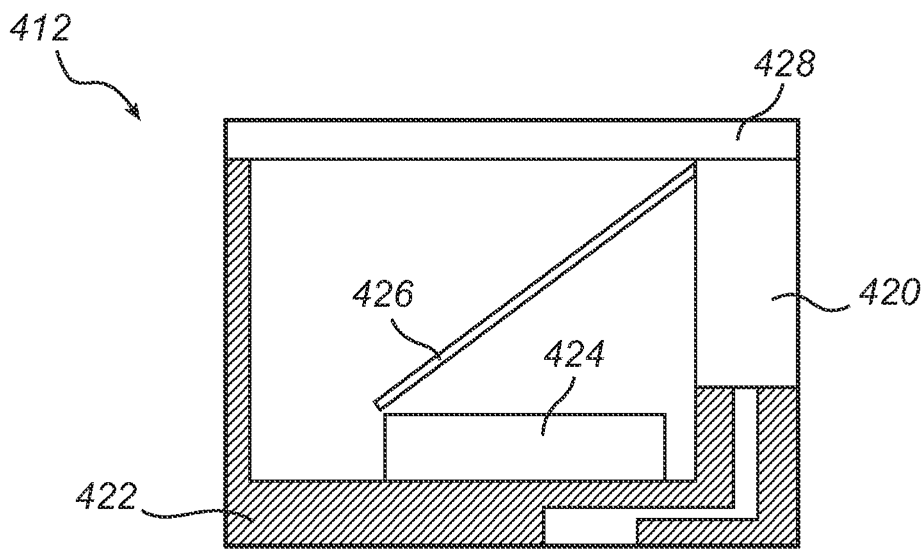

Fig. 12

LED MODULE

FIELD OF THE INVENTION

The present invention relates to a lightsource, comprising a LED chip adapted for emitting excitation light in a first wavelength range; a wavelength converter adapted for converting excitation light to converted light in a second wavelength range; and a reflector, adapted for transmitting converted light, and for reflecting excitation light onto the wavelength converter.

BACKGROUND OF THE INVENTION

U.S. Pat. No. 7,245,072 B2 discloses a LED module comprising a LED, a layer of a phosphor material, and a birefringent polymeric multi-layer reflection filter. The phosphor material, which is located between the reflection filter and the LED, emits visible light when illuminated with ultraviolet (UV) excitation light by the LED, and the filter serves for removing remaining, unconverted UV light from the optical output of the LED module. By using birefringent polymers in the reflector layer, better filtering of UV light having an oblique angle of incidence onto the filter is reported.

The use of multiple birefringent layers in the reflector however leads to complicated devices and/or fabrication methods.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a less complicated technique for removing excitation light from the light output of a LED module. To this end, there is provided a lightsource, comprising a LED chip adapted for emitting excitation light in a first wavelength range; a wavelength converter adapted for converting excitation light to converted light in a second wavelength range; a reflector, adapted for transmitting converted light, and for reflecting excitation light onto the wavelength converter; and an absorption layer, arranged for absorbing unconverted excitation light. The absorption layer assists in decreasing the amount of emitted excitation light.

Preferably, the reflector is a multi-layer reflector comprising a plurality of alternating layers of at least two different materials having at least two different indices of refraction. Such reflectors may be given a high wavelength selectivity at a substantially normal angle of incidence of the light.

Preferably, the absorption layer is located between layers of the reflector. This configuration may even further reduce the amount of transmitted excitation light impinging on the reflector at an angle of incidence that deviates from the reflection filter's surface normal, and/or reduce the required number of process steps in the fabrication of an efficient filter. More preferably, at least one fourth of the total number of reflector layers is located on each side of the absorber.

Preferably, the wavelength converter is located between the reflector and the LED chip, as this configuration is beneficial from a conversion efficiency point of view. Preferably, the reflector, the absorption layer, the wavelength converter and the LED chip are joined to form a single device. This is a very compact and efficient configuration that is inexpensive to fabricate.

Preferably, the multi-layer reflector and the absorber have a total thickness of less than 2000 nm.

BRIEF DESCRIPTION OF THE DRAWINGS

This and other aspects of the present invention will now be described in more detail, with reference to the appended drawings showing a currently preferred embodiment of the invention.

FIG. **1** is a schematic sectional view of a LED module comprising a LED chip, luminescent converter, a reflector and an absorber.

FIG. **2** is a schematic sectional view of the LED and the luminescent converter in FIG. **1**.

FIG. **3** is a schematic sectional view of a LED module laving the luminescent converter, reflector, and absorber integrated with the LED chip.

FIG. **4** is a schematic sectional view of the LED in FIG. **3**.

FIG. **5** is a graph, illustrating the transmittance of a multilayer reflector.

FIG. **6** is a graph, illustrating the transmittance of a multilayer reflector comprising an absorber layer.

FIG. **7** is a schematic sectional view of a LED module, showing an alternative geometric configuration of the luminescent converter and the reflector.

FIG. **8** is a schematic sectional view of the LED, the luminescent converter, and the reflector in FIG. **7**.

FIG. **9** is a schematic sectional view of a LED module, showing yet another alternative geometric configuration of the luminescent converter and the reflector.

FIG. **10** is a schematic sectional view of the LED and the reflector in FIG. **9**.

FIG. **11** is a schematic sectional view of a LED module, showing still another alternative geometric configuration of the luminescent converter and the reflector.

FIG. **12** is a schematic sectional view of the LED and the reflector in FIG. **11**.

DETAILED DESCRIPTION

Light emitting diodes, LEDs, are used her a wide variety of applications. Often, a luminescent converter is integrated into the LED module to create light of a different color than the light originally emitted from the LED.

In order to obtain a pure color of the light emitted from a LED module using luminescent conversion, it is important that no excitation light be allowed to exit from the LED module. This is particularly important in applications where the required color temperature is specified by standards and regulations. To this end, a filter is sometimes disposed in the LED module in order to filter away any remaining excitation light from the LED module output.

FIG. **1** schematically illustrates an exemplary embodiment of a LED module **10** comprising a LED **12**. The LED **12** is fed with electrical current via terminals **14**, **16**, and the output light of the LED **12** is coupled out of the LED module **10** via an essentially hemispherical lens **18**. The LED is arranged to emit ultraviolet (UV) light, and a phosphor layer **24** converts the UV light to white light, i.e. to a mixture of red, green, and blue light. Total conversion of the UV light is not achieved as the phosphor layer would then have to be too thick, leading to a high re-absorption of red, green, and blue light. Therefore, in order to reduce the emission of UV light from the module **10**, the lens **18** comprises a reflector **26**, which reflects UV light and transmits visible light. A wavelength selective absorption layer **28** on the surface of the lens significantly reduces any leakage of UV light. The wavelength selectivity of the absorption layer **28** is such that its absorption is higher in the UV wavelength range than in the visible wavelength range. Throughout this disclosure, an absorption layer is defined as a layer consisting of material(s) having an extinction coefficient k>0.005 in the excitation wavelength range. An absorption layer is intended to be located in the light path from the light emitting surface of the LED chip and/or the luminescent converter, to the LED module tight output surface; structures such as electrical wiring, opaque LED chip submounts or the like are not considered absorber layers in this sense.

FIG. **2** shows the LED **12** and the phosphor layer **24** of FIG. **1** more in detail. A LED chip **20** is located on a submount **22**. Electrical current is fed to the top electrode of the LED chip **20** through a wire **30**.

FIG. **3** schematically illustrates an exemplary embodiment of a LED module **110** comprising a LED **112**.

FIG. **4** shows the LED **112** of FIG. **3** more in detail. A LED chip **120** is flip-chip mounted onto a submount **122**. Electrical current is fed to the top electrode of the LED chip **120** through a conductor **130** in a via-hole. The LED chip **120** emits blue excitation light in the wavelength range 400-470 nm, with a peak wavelength of about 450 nm. The excitation light is converted to amber light at about 600 nm by a luminescent phosphor material layer **124** attached to or deposited on the LED chip **120**; in this particular example, the phosphor material is a LUMIRAMIC® comprising $(BaSr)_2Si_5N_8$:Eu, i.e. Barium Strontium Silicon Nitride doped with Europium. Its emission wavelength characteristic may be varied by changing the ratio between Barium and Strontium; in this case, 85% Ba and 15% Sr is used. On top of the LUMIRAMIC® layer **124**, there is a multi-layer reflector coating **126**, which incorporates an absorbing layer. Locating the reflector directly on the LUMIRAMIC® layer has the advantage of reflecting back a larger portion of the unconverted excitation light onto the LUMIRAMIC® layer, and thus increasing the conversion efficiency.

A multi-layer reflector is a type of interference filter that consists of several alternating layers having different indices of refraction; their wavelength response can be designed relatively freely, and they can be designed to give a high suppression of the excitation light. Multi-layer reflectors are therefore very well suited for removing excitation light from the LED module output.

However, as the transparency of a typical interference filter coating varies with the angle of incidence of the light impinging on the interference fitter coating, some excitation light will leak through the filter due to the fact that LEDs and wavelength converters typically do not produce a collimated output.

Table 1 gives an example of the structure of a multi-layer reflector that is not provided with an internal absorber layer; its corresponding transmittance as a function of angle of incidence, relative to the reflector surface normal, is given in FIG. **5**. The fitter is made up of alternating layers of SiO_2, having a refractive index of approx. 1.46, and Nb_2O_5, with a refractive index of approx. 2.39. Layer no. 1 is adjacent to a LUMIRAMIC® converter, and layer no. 41 is adjacent to a lens having a refractive index of about 1.5; d signifies the thickness of each layer in nanometers.

TABLE 1

Layer	Material	d (nm)
1	Nb_2O_5	22.43
2	SiO_2	47.46
3	Nb_2O_5	58.51
4	SiO_2	37.19
5	Nb_2O_5	56.08
6	SiO_2	58.00
7	Nb_2O_5	167.17
8	SiO_2	61.99
9	Nb_2O_5	163.83
10	SiO_2	62.79
11	Nb_2O_5	164.02
12	SiO_2	86.66
13	Nb_2O_5	31.59
14	SiO_2	86.17
15	Nb_2O_5	38.59
16	SiO_2	78.94
17	Nb_2O_5	56.06
18	SiO_2	32.39
19	Nb_2O_5	81.56
20	SiO_2	39.43
21	Nb_2O_5	179.54
22	SiO_2	55.61
23	Nb_2O_5	164.17
24	SiO_2	67.07
25	Nb_2O_5	162.12
26	SiO_2	60.98
27	Nb_2O_5	74.36
28	SiO_2	21.77
29	Nb_2O_5	63.28
30	SiO_2	52.35
31	Nb_2O_5	295.69
32	SiO_2	51.12
33	Nb_2O_5	159.13
34	SiO_2	71.99
35	Nb_2O_5	154.03
36	SiO_2	72.77
37	Nb_2O_5	153.48
38	SiO_2	63.71
39	Nb_2O_5	146.28
40	SiO_2	77.15
41	Nb_2O_5	5.71
	Total Thickness	3583.18

Table 2 gives an example of the structure of the multi-layer reflector **126** of the LED module described above with reference to FIGS. **2-3**, wherein the filter incorporates an integrated absorber layer of Fe_2O_3. The filter's transmittance as a function of angle of incidence is given in FIG. **6**. Layer no. 1 is adjacent to the LUMIRAMIC® converter **124** and layer no. 17 is adjacent to the lens **18**, which consists of SiO_2. Note that the thickness of the reflection filter is approximately one third of the thickness of the reflection filter of table it. Also, the absorber layer is an integral part of the reflector and contributes to the reflective properties of the device, since Fe_2O_3 has an index of refraction of 3.11, significantly different from the index of refraction of the adjacent Nb_2O_5 layers. The reflection filter multilayer structure surrounding the thin absorbing Fe_2O_3 layer, on the other hand, enhances the absorption of the thin Fe_2O_3 layer.

TABLE 2

Layer	Material	d (nm)
1	Nb_2O_5	149.61
2	SiO_2	46.59
3	Nb_2O_5	162.56
4	SiO_2	59.38
5	Nb_2O_5	160.02
6	SiO_2	62.68
7	Nb_2O_5	78.00
8	Fe_2O_3	8.40
9	Nb_2O_5	80.66
10	SiO_2	64.37
11	Nb_2O_5	46.08

TABLE 2-continued

Layer	Material	d (nm)
12	SiO_2	72.79
13	Nb_2O_5	31.75
14	SiO_2	95.16
15	Nb_2O_5	44.42
16	SiO_2	53.56
17	Nb_2O_5	31.17
Total Thickness		1247.19

The significant difference between the angular dependencies of the two filters of the graphs in FIGS. **5**-**6** is impressive. By integrating only a thin layer of an absorber into the filter, the filter can not only be made thinner and fabricated using fewer process steps; also the angular dependency of the transmittance of blue light is significantly reduced, and higher-order transmission spikes at low angles are removed.

FIG. **7** schematically illustrates an exemplary embodiment of a LED module **210** comprising a LED **212** and a separate phosphor/reflector/absorber portion **224**/**226**. The configuration of the LED **212** and the phosphor/reflector/absorber portion is illustrated more in detail in FIG. **8**, which shows a multi-layer reflector **226**, comprising a plurality of transparent, alternating reflector layers and a plurality of integrated absorber layers deposited onto a layer of phosphor **224**.

FIGS. **9** and **10** illustrate an alternative geometry of the LED module, wherein the LED chip **320** and the luminescent converter **324** are mounted side by side on a submount **322**. Excitation light from the LED chip is reflected onto the luminescent converter **324** by an essentially parabolic multi-layer reflector **326**, which also incorporates an absorber layer. The reflector **326** is arranged to transmit the converted light from the luminescent converter, and the absorption layer reduces the reflector's **326** transmission of any excitation light impinging on the reflector **326** at substantially oblique angles.

The geometric separation of the LED chip **320** and the luminescent converter **324** also makes it possible to locate and extend a separate hemispherical absorber (not shown) around the luminescent converter, such that converted light from the luminescent converter will pass through the separate absorber at a normal angle of incidence, and excitation light leaking through the reflector will pass through the separate absorber at an oblique angle. This will mike the path through the absorber longer for the excitation light than for the converted light.

FIGS. **11** and **12** show an embodiment illustrating how a geometric separation of the LED chip from the luminescent converter may enable different absorption levels of excitation light and converted light, respectively, and thereby contribute to improving the colour temperature of a LED module. A wavelength selective reflector **426** reflects the light from a LED chip **420** onto a luminescent converter **424**. Converted light from the luminescent converter passes through the reflector, and then through an absorber **428** at a normal angle of incidence. Any excitation light from the LED chip **420** that may leak through the wavelength selective reflector **426** will pass through the absorber **428** at an oblique angle. This will make the path through the absorber **428** longer for the excitation light than for the converted light.

In summary, the invention relates to a LED module which converts pump light from a LED chip to light at another wavelength, which is emitted from the module. The conversion takes place in a portion of a luminescent material. The color purity of the LED module is enhanced by reducing any leakage of pump light using a reflector in combination with an absorber. In one embodiment, the absorber is integrated as one or several thin absorbing layers between the layers of a multi-layer interference filter; this may yield an even higher reduction of pump light leakage from the module.

The person skilled in the art realizes that the present invention by no means is limited to the preferred embodiments described above. On the contrary, many modifications **110** and variations are possible within the scope of the appended claims. For example, the invention is not limited to absorption layers of Fe_2O_3; also other materials featuring an absorption in the excitation wavelength range may be used, for example but not limited to zinc iron oxide, titanium iron oxide, vanadium oxide, bismuth oxide, copper oxide, bismuth vanadate, zirconium praseodymium silicate, or any mixture thereof.

Neither is the invention limited to luminescent layers of LUMIRAMIC® or other phosphorescent materials; any atomic or molecular species or solid-state compounds that convert at least a part of incident electromagnetic radiation to electromagnetic radiation with a characteristic signature may be used, such as fluorescent dyes or luminescent quantum dots.

In the examples above, the multi-layer reflectors comprise alternating layers of Nb_2O_5 and SiO_2. Other combinations of two or more different materials, having different indices of refraction, may be used and are covered by the appended claims. Further, the reflector is not limited to multi-layer reflectors; any type of wavelength selective reflector capable of reflecting the excitation wavelength while at the same time transmitting the converted wavelength may be used. The absorber may consist of one or several absorbing layers integrated in the reflector, or it may be a separate absorber located elsewhere in the LED module. Even though the entire LED module preferably is comprised in a single housing, it may also be divided between separate housings. Different parts of the device may be separated between different modules, which, when cooperating, obtain the same function as claimed. Further, even though in the examples above, blue or UV light is used to generate amber or white light, other combinations are also covered by the appended claims. The invention is not limited to LED chips or luminescent converters emitting visible light; they may as well emit in the IR and UV regions. Nor is the invention limited to LED:s emitting excitation light in a broadband optical spectrum. Also narrow-band LED:s incorporating any type of optical feed-back and stimulated emission, such as diode lasers, are within the scope of the claim. Features disclosed in separate embodiments in the description above may be advantageously combined.

The use of the indefinite article "a" or "an" in this disclosure does not exclude a plurality. Any reference signs in the claims should not be construed as limiting the scope.

The invention claimed is:

1. A light source, comprising

a LED chip for emitting excitation light in a first wavelength range;

a wavelength converter for converting excitation light to converted light in a second wavelength range;

a multi-layer reflector for transmitting converted light, and for reflecting excitation light onto the wavelength converter, the reflector comprising a plurality of alternating layers of at least two different materials having at least two different indices of refraction;

an absorption layer, arranged for absorbing unconverted excitation light and located between layers of the multi-layer reflector; and a separate hemispherical absorber positioned around the luminescent wavelength converter so that converted light from the luminescent wavelength converter passes through the separate hemispherical absorber at a normal angle of incidence and excitation light leaking through the multi-layer reflector passes through the separate hemispherical absorber at an oblique angle.

2. The light source according to claim **1**, wherein the wavelength converter is located between the multi-layer reflector and the LED chip.

3. The light source according to claim **2**, wherein the multi-layer reflector, the absorption layer, the wavelength converter and the LED chip are joined to form a single stack.

4. The light source according to claim **1**, wherein at least one fourth of the total number of multi-layer reflector layers is located on each side of the absorption layer.

5. The light source according to claim **1**, wherein the multi-layer reflector is parabolic.

6. The light source of claim **1**, further comprising a lens enclosing the LED chip, the luminescent wavelength converter and the multi-layer reflector incorporating the absorption layer.

7. The light source of claim **6**, wherein the lens is hemispherical.

8. A light-emitting diode (LED) module comprising:

a light-emitting diode (LED) chip and a luminescent wavelength converter mounted side by side on a sub-mount;

a pair of electrical terminals providing electrical current to the LED chip;

a parabolic multi-layer reflector incorporating an absorption layer;

a hemispherical lens enclosing the LED chip, the luminescent wavelength converter mounted side by side on the sub-mount and the parabolic multi-layer reflector incorporating the absorption layer; and

a separate hemispherical absorber positioned around the luminescent wavelength converter so that converted light from the luminescent wavelength converter passes through the separate hemispherical absorber at a normal angle of incidence and excitation light leaking through the reflector parabolic multi-layer reflector passes through the separate hemispherical absorber at an oblique angle.

9. The LED module of claim **8**, wherein the LED chip emits excitation light in a first wavelength range.

10. The LED module of claim **9**, wherein the wavelength converter converts excitation light to converted light in a second wavelength range.

11. The LED module of claim **8**, wherein the parabolic multi-layer reflector comprises a plurality of alternating layers of at least two different materials having at least two different indices of refraction.

12. The LED module of claim **8**, wherein the incorporated absorption layer reduces the parabolic multi-layer reflector's transmission of any excitation light impinging on the parabolic multi-layer reflector at substantially oblique angles.

* * * * *